A CONCEPTUAL FRAMEWORK FOR DESIGN AND CONSTRUCTION INFORMATION

K. Karstila[a], B-C. Björk[a] and M. Hannus[b]

[a]Laboratory of Urban Planning and Building Design
Technical Research Centre of Finland
Espoo, Finland

[b]Laboratory of Structural Engineering
Technical Research Centre of Finland
Espoo, Finland

Abstract

This paper tries to sketch out a conceptual framework model for design and construction information. This conceptual model is formed by extending the finnish RATAS building product data model to include also construction activities, resources, costs, organizations, contracts, etc. and relationships between them. The overall conceptual framework model can be used to extract conceptual submodels related to the information needs of particular participants of the construction process. As an example of different views to design and construction information the views of design, cost estimating and production planning discussed in the paper. The framework model can also be used to define the position of traditional classification systems and general databases in the construction information process.

1. INTRODUCTION

In contrast to many other industries the construction industry can show no record over the past two or three decades of a consistent growth in productivity, or of an overall increase in the quality or performance of the end product. Prefabrication of building componenents is one of the few cures for this stagnation which has been tried, but the results have been equivocal. Some cost reductions have been achieved, but often the resulting buildings have been dull and even technically deficient.

During the coming decades there are a number of potential remedies, which could be tried for revitalizing the construction industries of the developed countries. Better management of information throughout the design and construction process is one, quality assurance systems is another and factory automation and on-site robotics is a third. Also organizational changes are proposed, in order to promote competition. In this paper we will concentrate on the first of these remedies and suggest some possible methods which could be useful in achieving the future visionary state termed computer integrated construction (Wright 1988; CIB 1990; Howard et al. 1989) or computer integrated design and construction by other authors.

Current methods of data management in construction are the result of a slow evolutionary process which has continued for centuries. The addition of some new technologies, such as CAD-systems and telefaxes, has done little to change the actual information management methods. The effects of high tech has mainly been the speeding up of some subprocesses, not a revolution in fundamental methods.

In a typical design and construction project of today there is a lot of duplication of data and especially of input of data. This is true even if most of the data is prepared using software tools such as word processors, spreadsheets, draughting systems, databases. Already the transfer of data between CAD-systems offers problems, despite the solutions offered by the IGES standard and the DXF defacto standard. The transfer of information between dissimilar software categories is virtually impossible on a general level, and only tailored, company specific solution exist.

In a prestudy initiated by the Technical Research Centre of Finland the concept of computer integrated construction was studied and some building blocks needed to achieve it were defined.

Future computer integrated construction will include extensive use of information technology in various phases and in various tasks of construction project, and especially integrated data management of these phases and tasks. Integration is done by means of commonly shared data stored by computers and data transfer between participants by eletronic data exchange. Production automation and robotics are features associated to computer integrated construction. Basic components needed to implement computer integrated costruction are:

* Computer hardware in wide use among different participants
* Application software:
  - CAD, based on product modelling approach
  - database systems
  - expert systems
* Standards for structuring construction information:
  - product data model standards
  - data exchange standards
  - EDI standards
  - bar code standards
  - other codes
* General data and knowledge bases
* Telecommunication networks.

One of the lessons learnt in the process of developing methods for data transfer between similar software systems (i.e. CAD systems) is the need to explicitly formulate the data structures used in both the different application programs and in the neutral transfer data formats which are needed to avoid the combinatorial explosion of bilateral conversion programs (Kelly 1986). The technique used for this purpose is called conceptual modelling and will be explained more in detail in the next section.

Conceptual modelling techniques are today used in the process of defining product data models, that is models which specify the information content of descriptions of products to be designed and manufactured by man. Such methods are in particular used in the definition of the future STEP-standard, Standard for the Exchange of Product Data, in the US known as PDES, (ISO 1988). A number of proposals have also been made for the basic structure of building product data models (Gielingh 1989; Björk 1989).

There a very few examples of the proposed use of conceptual modelling techniques for other types of construction information than design data (for example see Luiten et al. 1990). The use of graphical activity modelling techniques such as IDEF0 or the related SADT for modelling seem to have more advocates (Sanvido 1990).

Using the same techniques for modelling all types of construction information would, however, offer significant benefits, especially when it comes to integrating applications dealing with different domains of information. Today there are ongoing international and national standardization activities in areas such as EDI (electronic data interchange of commercial documents), databases for standard parts, CAD data exchange, building classification systems etc. which could benefit a lot from the use of similar conceptual modelling techniques and from the integration of their actual data structures.

The synopsis of this paper is as follows. In section two the techniques of conceptual modelling are presented. Section three discusses the need for product data model extensions. Section four outlines a generic conceptual model of construction information. Section five contains some examples of application dependant views which could be extracted from the generic model. The last section tries to summarize the paper, to put this research effort into perspective and to suggest some short and long term goals for possible research and standardization efforts.

2. CONCEPTUAL MODELLING

Conceptual models are used in modelling information of a specific domain or the content of database. A conceptual model describes the semantics of that information i.e. categories and structure of information, not the format (syntax) in which information it stored. Conceptual model defines different information entities or objects of the domain and relationships between the entities. Conceptual models modelling product information, e.g. building information, are called product data models.

There are various modelling techniques for defining conceptual models. Every modelling technique or data definition language of a database management systems is based on specific data model. A data model provides basic concepts or tools for describing data, data relationships, data semantics and constraints of conceptual models or databases. Common data models in database management systems are e.g. network and relational models. For a brief overview of the role of conceptual models, data models etc. in the context of building product models see Björk & Penttilä (1989).

Modelling techniques used in product modelling work are also based on specific data models. In the international STEP work modelling techniques such as IDEF1X, NIAM and the data definition language EXPRESS are used in defining product data models. IDEF1X is explained here shortly because we use it later on in this paper.

Basic concept of IDEF1X model are shown in figure 1, are

* Entities or objects describing real world concepts are represented as boxes. Entities have attributes describing different properties of entities and in entity instances attributes will get specific values. Some attributes are key attribute(s), primary key, by which unique instances of entities can be identified.
* Relationships between entities are represented as lines between boxes. Cardinalities (one-to-many and many-to-many) are expressed by dots at the end of lines.
* Categorization defines subtypes of general entities, so that supertype holds common attributes to all subtypes and subtype having their own specific attributes. Categorization in a way implements "inheretance" of attributes, a feature stemming from object oriented data models.

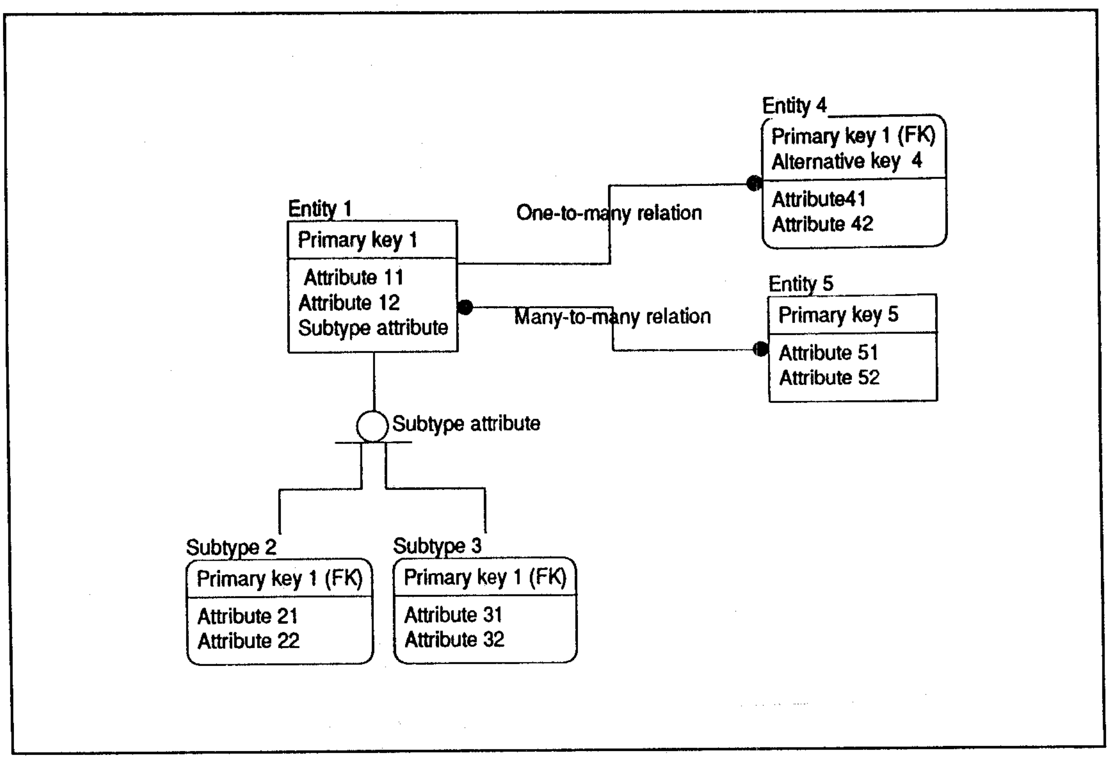

Figure 1. Basic concepts of IDEF1X modelling technique.

The IDEF1X modelling technique is closely connected to the design of relational databases. That is why IDEF1X models are in final format presented in normalized form, meaning e.g. that no many-to-many carninalities are allowed. Each many-to-many relationship is decomposed into a pair of one-to-many relationship using an intermediate "relationship" entity. Also there are rules how a primary key is migrated from one entity to become a foreign key in another entity which is dependant on first one, that is being in identifying relationship to it.

In this paper our aim is on a general level to show the framework's main entities and their relationship in a conceptual model and because of that model is not in normalized form and not all the attributes of entities are showed.

While IDEF1X is used for modelling information, activity modelling techniques are used in modelling various activities of processes, such as the construction process, and data and material flows in the processes. Also mechanisms (agents performing activities) and control of activities are presented in activity diagrams. The most commonly used activity modelling technique is IDEF0 or the closely related SADT. The basic concepts of an IDEF0 model and an example of part of a model are shown is figure 2.

IDEF0 models are hierarchic so that activities can be broken into other activities on a lower level which in turn can broken into new activities and so on down to the desired level.

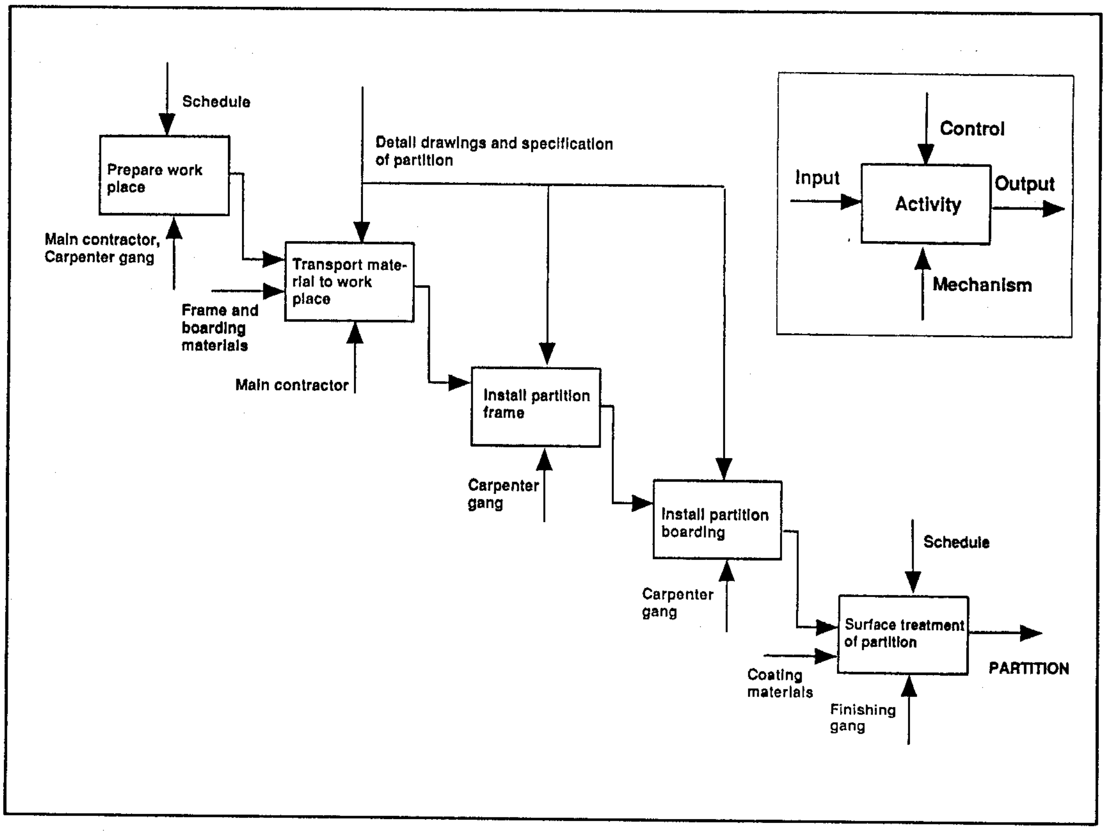

Figure 2. Basic concepts of the IDEF0 activity modelling technique and an example (installation of partition wall) of part of a model.

3. NEED FOR EXTENSION OF PRODUCT DATA MODELS

Work in defining building product data models, such as the development work with the RATAS building product model in Finland, is still in its beginning. Already it can be seen that there are some shortcomings in the current product data models. Work with product data models have often started from the designer's viewpoint and that is one reason why product data models usually cover only product data. Construction projects include, however, also lots of other information than just product data; e.g. data concerning production methods, schedules, costs, organizations, contracts, etc. Adding the contractor's and building owner's information needs would necessiate expansion of the domain covered by building product data models.

On the other hand activity models are used in describing production processes, activities of companies etc. Activity models can be used in development projects as analysis tools of the present state of the process, and in that way possible bottlenecks in the process are identified. After that an improved, target process model is being developed. Activity models have poor expressiveness in describing the data and the structure of data and its relationships to the model's data flows between activities. Often parallel with activity modelling, conceptual modelling is used in describing the data of the domain.

In trying to develope integrated data management for the construction process it is worth aiming towards a comprehensive, single conceptual model describing design and other construction information. If different participants in the construction process define totally own models there is a danger that resulting models are incompatible already in their basic elements. This would cause problems in the data exchange between the participants because conversion of information from model to another would be needed. On the other hand if the models of different participants are submodels from single coherent model there would be no need for such conversions. If single conceptual model cannot be developed, at least different modelling efforts should be co-ordinated in the domain of the information involved in data exchange between different participants.

The introduction of new potential applications dealing with other construction information than design data, such as project planning, document management systems and EDI, also require extension of the building product data models. A more comprehensive discussion of current modelling efforts and the techniques used, as well as their relation to a proposed conceptual framework for design and construction information can be found in Björk 91.

4. CONCEPTUAL MODEL FOR DESIGN AND CONSTRUCTION INFORMATION

4.1. RATAS building product data model

In Finnish research and development work concerning information technology in construction a building product data model, called the RATAS-model, is being developed. Already concensus about the general principles of RATAS-model have been achieved. At the moment work aims at refining the ideas and to standardize at least some of the object classes and their relationships, also prototyping is being done. The RATAS-model consist of objects whose attributes are defined by object class. Class hierarchies can be used for inheriting attribute definitions from superclass to subclasses. Product structure is formed by part-of and connected-to relationships. Part-of relationships are used for aggregating object from its components. Connected-to relationships are used for other meaningful relationships. Five different abstraction hierarchy levels are defined for structuring the RATAS-model. These levels are:

* Building. Including building itself.
* System. Spatial, structural, electrical, ventilation systems etc.
* Subsystem. Grouping method for division of systems into smaller objects: floors, flats, fire zones, etc.
* Part. Spaces and building components: rooms, columns, beams, radiators, etc.
* Detail. Subdivision of parts into more detailed components.

Part-of relationships are mostly between objects from different abstraction level and connected-to relationships are mostly between object on the same level. The general structure of RATAS-model and an example of one object (room) and its relationships are shown in figure 3.

In the work carried out in the RATAS III-project (Penttilä & Tiainen 1991) some fifty basic object classes and their main attributes have been defined. So far the RATAS-model covers only product data and its main development viewpoint has been building design. In the following we will present some extensions to the RATAS-model aiming to add cost estimating and production planning viewpoints into the model. Also the context for building codes and general production files is discussed. Analysis is done in a simplified manner and the results should be regarded as providing first sketches for discussion, not as the final result of thorough analysis.

4.2. Cost estimating

Cost estimating needs as an input a bill of quantities provided by the quantity take off process. Cost estimating done by building owner (developer) in early project phases is based on building components and standard cost files concerning these components. Standard cost files are annually published in Finland in book form, but also commercial cost estimating software providing these files are available.

The product modelling approach can be used for automatic quantity take off serving cost estimating. One possible software architecture is to use combination of CAD-system and database management system: the CAD-system acts as user interface and as a drawing/modelling system and the database system is used for managing quantity data. CAD-system should have standard building components in a symbol library. While the user is placing building components into a drawing, quantity data of those components is at the same time inserted into the database. In this application drawings are in

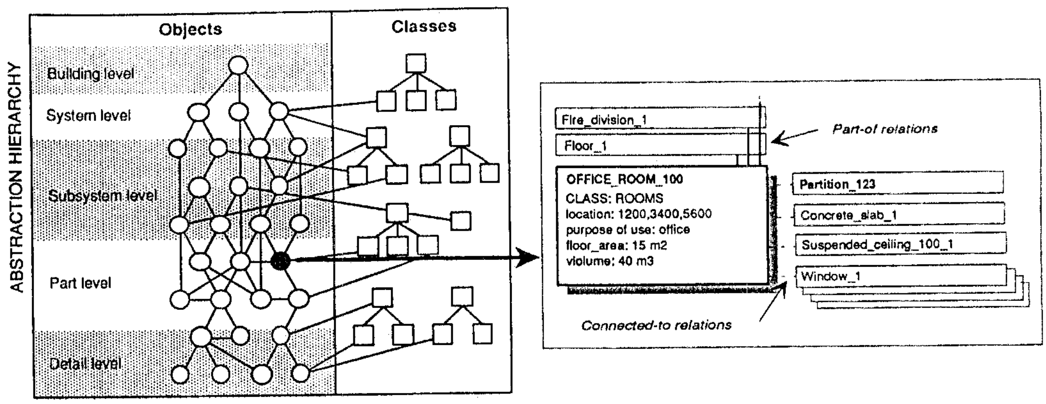

Figure 3. General structure of RATAS building product data model and an example of room object, its attributes and relationships to other objects. Vertical links from room object describe part-of relationships and horizontal links describe connected-to relationships.

CAD-system and only quantity data is in e.g. relational database. As a result the whole quantity database could be then transferred to a contractor for cost estimating and the database system could be used for generating different kinds of reports, tables etc. including quantity data. This kind of prototype system (figure 4) has been developed in the RATAS III-project.

Cost estimating done in this way, at the building component level, does not require extensions to the RATAS-model, because only product data (rough geometry) is involved in the data exchange between the CAD-system and the database system.

Cost estimating done by the contractor in later project phases and serving more sophisticated purposes is done on a more precise level by breaking building components into different resources (i.e. work, material, machines) needed for producing the building component. New concepts required to the RATAS product data model are (figure 5):

* Activity. Activities produce products as result. Activities can be broken through part-of relationships into subactivities.
* Resource use. Activities use resources. The actual consumption of resources (e.g. material rate) is stored in resource use.
* Resource. Resources include all possible resource types belonging into resource subcategories: work, material, machine.
* Cost. Resource use causes costs.

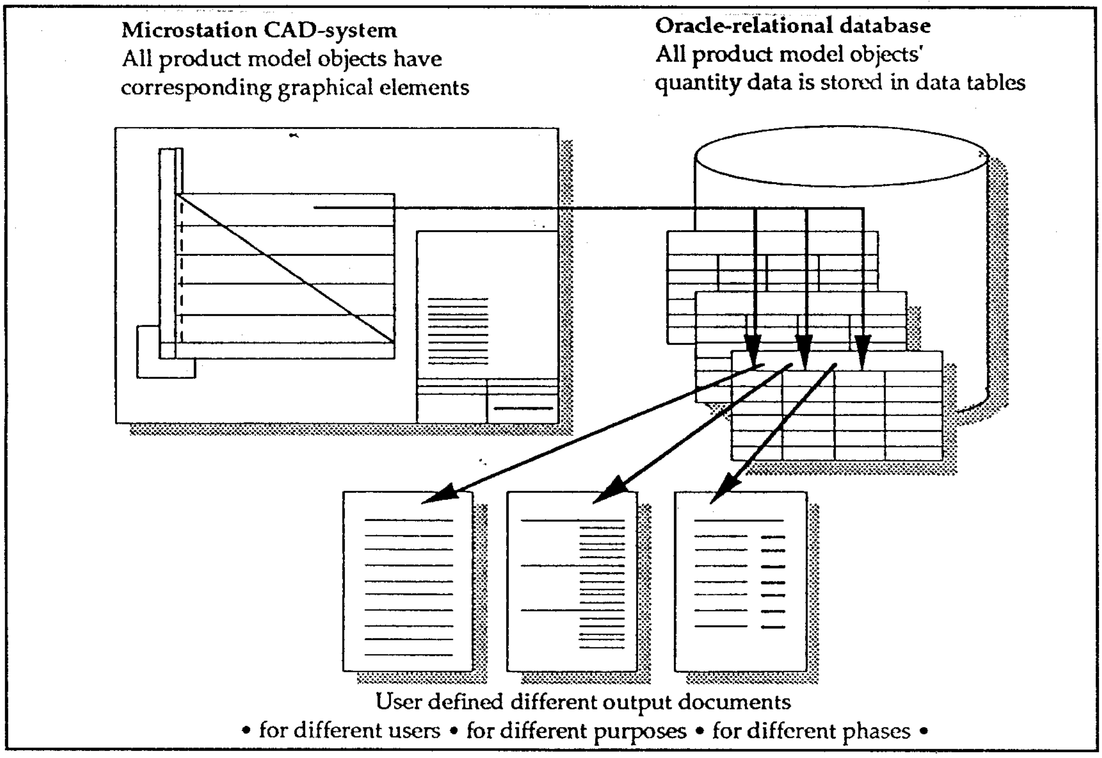

Figure 4. Basic structure of quantity data oriented product model prototype. (Penttilä & Tiainen 1991)

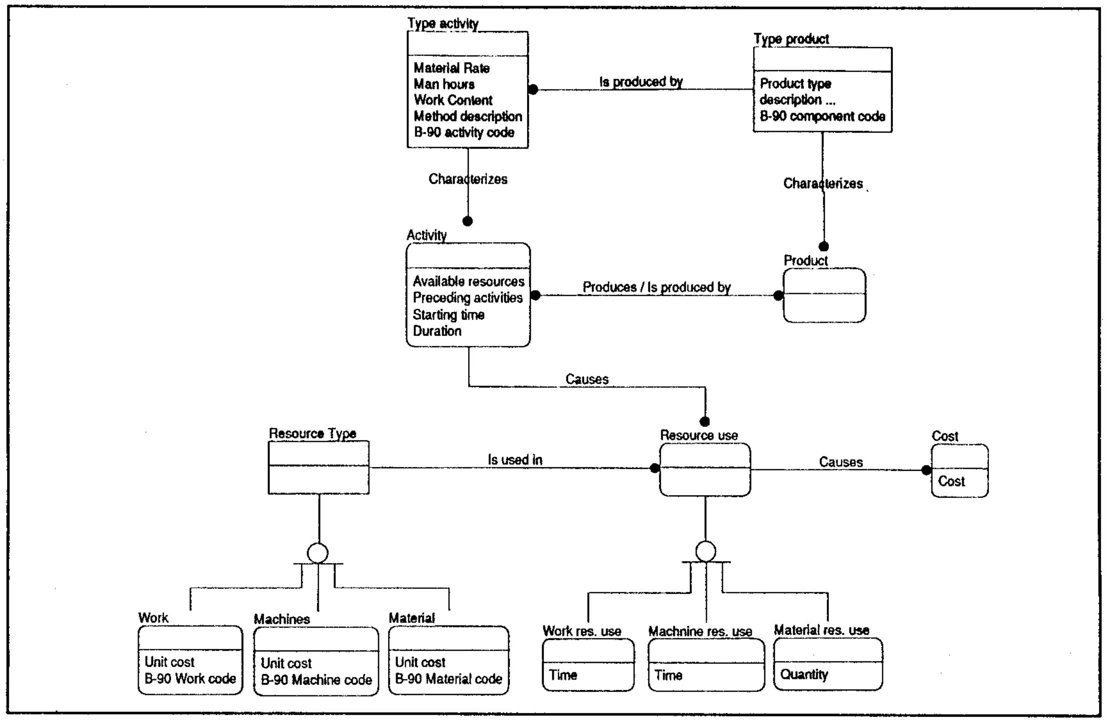

Figure 5. Activity, product, resource use and resource.

Type product and type activity concepts need more explaining. Building components which are results from activities can be categorized into types, such as gypsum partition wall or masonry partition wall etc. This kind of building component types and their properties can often be found in product data files and general databases. Also the activities producing these type products can be categorized into type activities having specific work contents and sequences, unit resource rates and method descriptions (all found in type activity description). In Finland this information can at the moment be found in the so-called RATU production files which are commonly used in production planning. Type activity entities are thus used as prototypes for actual instances of activities in the project.

Type Activities and type products are typical information which in the future can be found in general databases. Also some resources, like building materials, should be found in general databases.

Besides production files building classification systems are used for information management. In Finland the Building-90 code (B-90) includes three major subcodes: building component code, activity code, and building material code. This code system provides a grouping system for construction information to be used in many project documents (specifications, cost estimates, procurement plans etc.). It serves different views to information and data exchange between these views (figure 6). In the framework schema these codes can be seen as attributes in type activity, type product and resource entities.

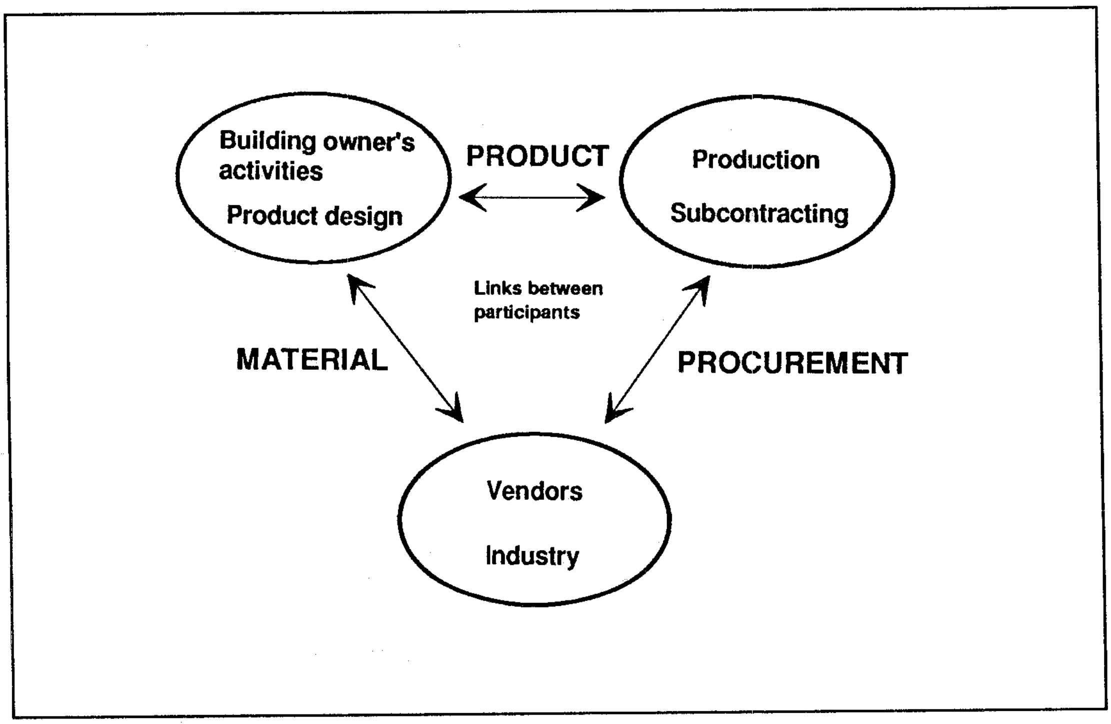

Figure 6. Building-90 codes and data exchange views. (Talo-90 1991)

Figure 7 shows how quantities from a product model can be converted into costs using the above mentioned concepts.

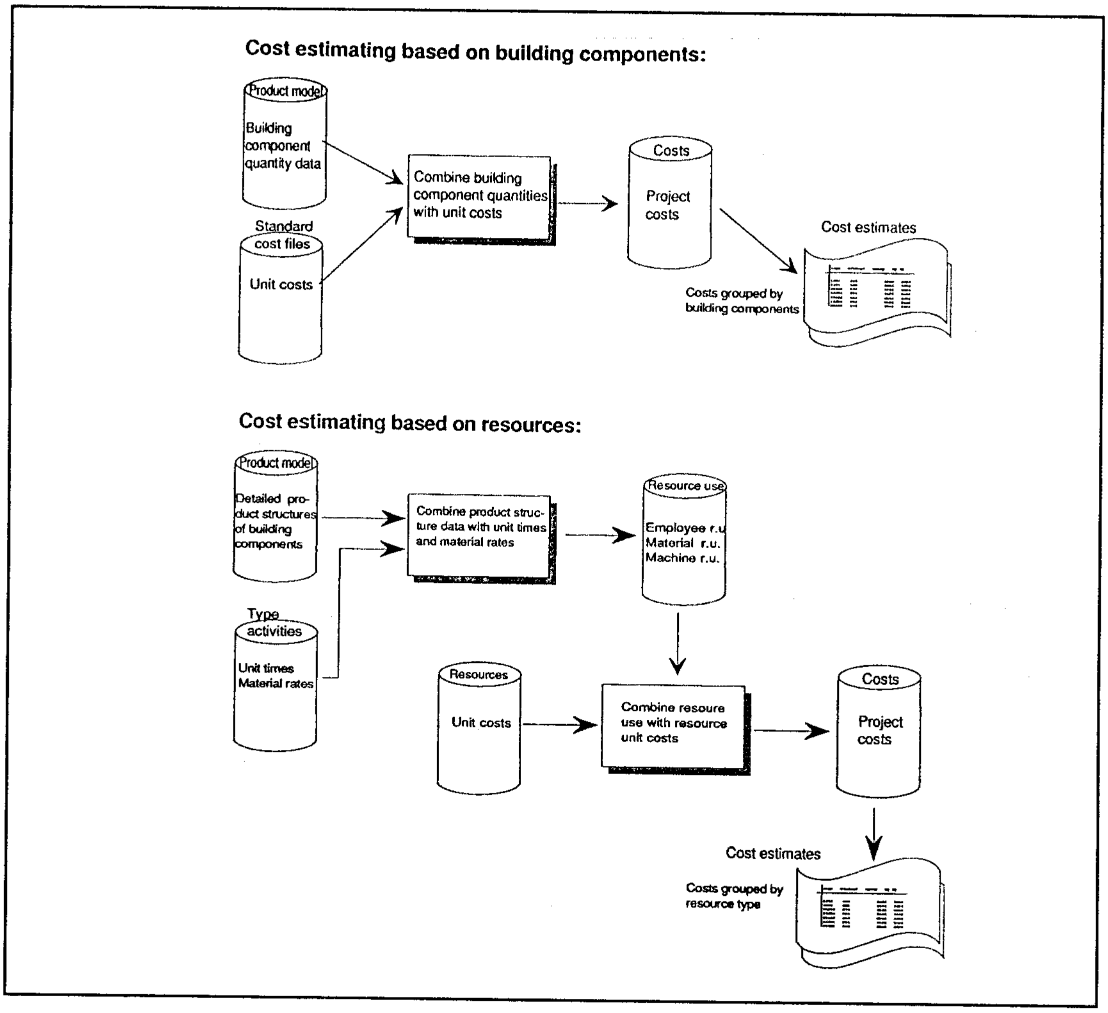

Figure 7. Cost estimating phases.

4.3. Production planning

In our simplified analysis production planning would not require new concepts, but adding some attributes to existing entities. Production planning uses also activity and resource use entities as basic input. The essential new point of view is time and scheduling. Various work methods, work sequences, resource input are compared on the basis of resulting costs and schedules.

New attributes in activity entities are available resources, the work's starting time, duration and preceding activities which here describe dependencies between activities. In practice more complex dependencies would be needed, but they are out of the scope of this paper. Important available resources are gang sizes and used machines.

Figure 8 shows simplified production planning phases using the above mentioned information.

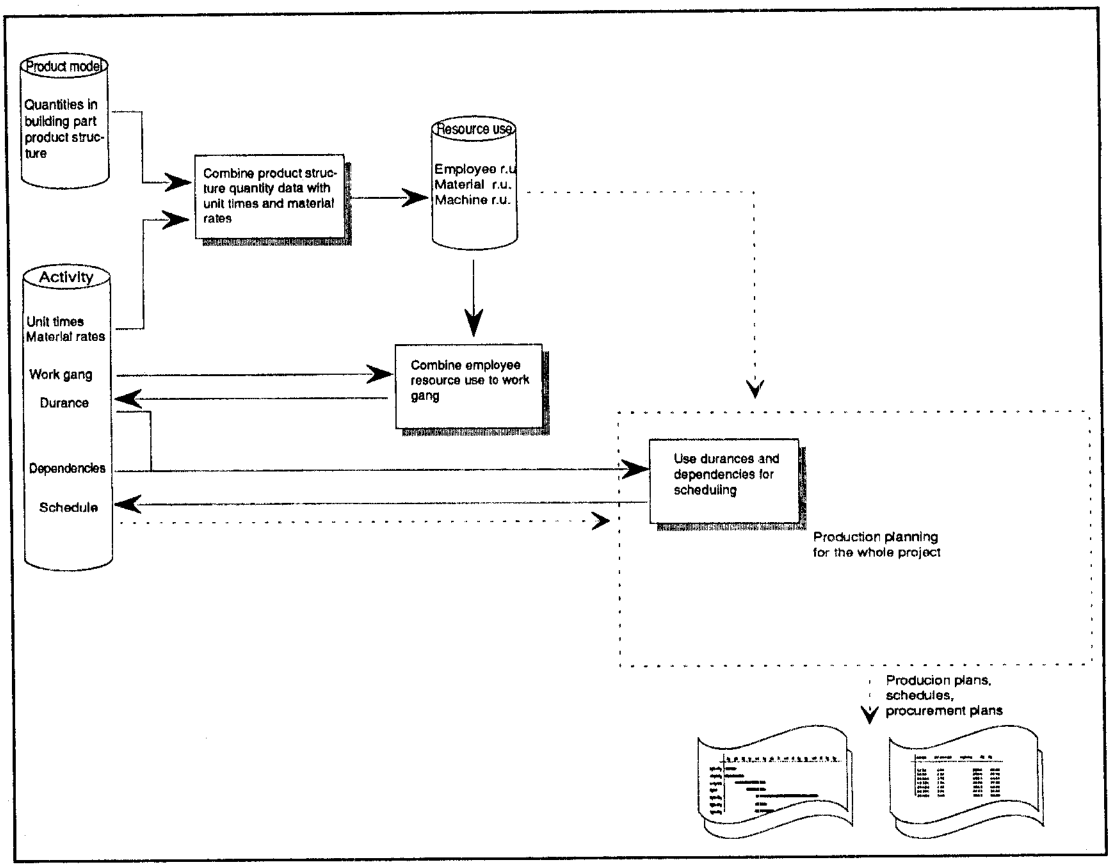

Figure 8. Using and generating data in production planning.

4.4. Other view points

Besides cost estimating and production planning views other product data model extensions would be envisaged. Describing different organizations involved in the construction process, contracts concerning different results and their relationships to activities might be useful from the building owner's viewpoint in developing project management and document management systems. Extending product entity to be result entity with other subcategories (services, information etc.) than products would faciliate modelling of intermediate results and their further use as resources (figure 9).

It can be seen that framework model covering all design and construction information would actually comprise many submodels (product/result, activity, organization, contract, resource, resource use and cost models) having their own structure and complex relationships between each other.

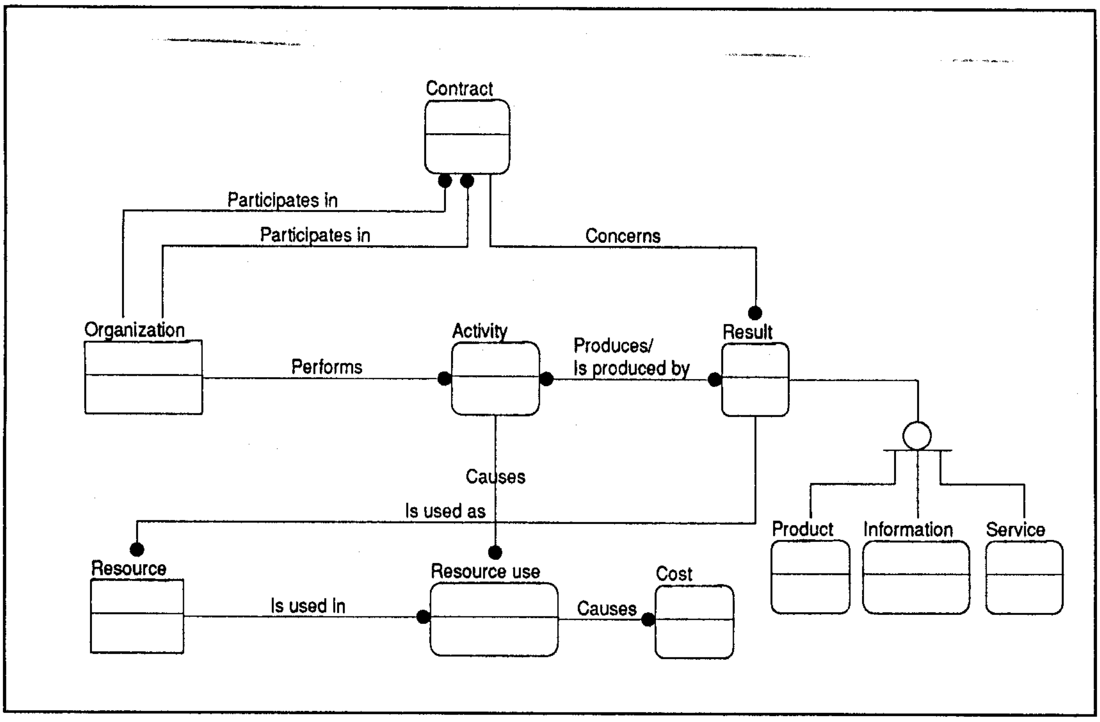

Figure 9. Modelling organizations, contracts, result subcategories.

5. EXTRACTION OF INFORMATION FOR DIFFERENT VIEWPOINTS

In order to make the ideas more concrete, a simple case is presented below. This case concerns the design and construction of a partition wall and it will be studied from the viewpoint of design, cost estimating and production planning.

5.1. Design

In the early design phase only the main functional requirements, sound proofing, fire proofing etc., and coarse geometry is defined as attributes of the partition object (figure 10). When a technical solution (to fullfill these functional requirements) for the partition is chosen more attribute values are fixed and partition object will be decomposed into subobjects linked to it with part-of relationships.

As an output from design we get the product's structure, materials and absolute quantities (here we present just quantities, actually we could have the geometry of the product from which quantity data is calculated).

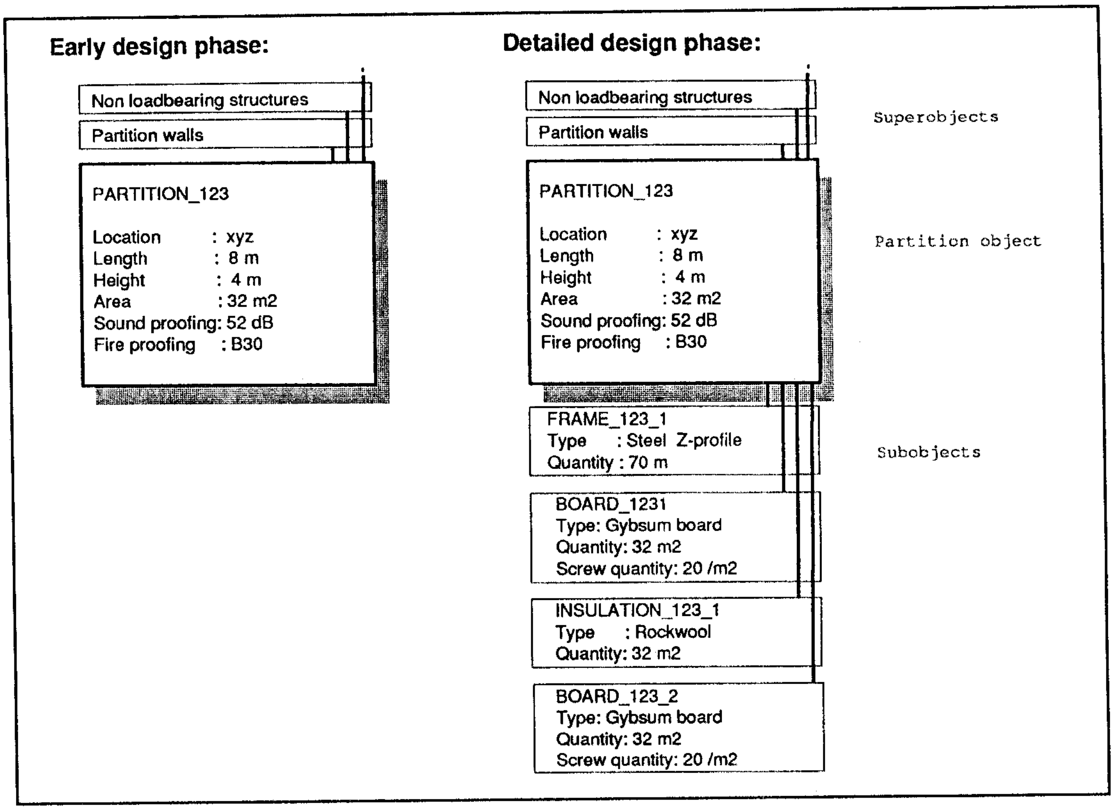

Figure 10. Partition object of product model and its attributes.

5.2. Cost estimating

Resource based cost estimating associated to the partition wall uses standard type product and chosen type activity information to get the structure and unit data (material and work rates) for the activity instances producing the partition. The resource use in question can be calculated using unit rates and quantity data from the product model (figure 11). Combining resource unit cost to resource use the actual building costs can be calculated. Building-90 codes could be used for grouping the resulting resource use and cost data of partition in cost estimates and procurement plans.

5.3. Production planning

Production planning (which here means definition of work duration and scheduling) uses partly same the resource use information as cost estimating. A new task is (figure 12) the definition of total duration of work on the basis of resource use and available resources (gang size) and work sequences. The break down of the partition installation activity into work sequences comes from an type activity library.

Resource use, work content and activity's dependencies to other activities (work) are basic information to be used in production planning concerning larger work entities and the whole project, its resources and schedules.

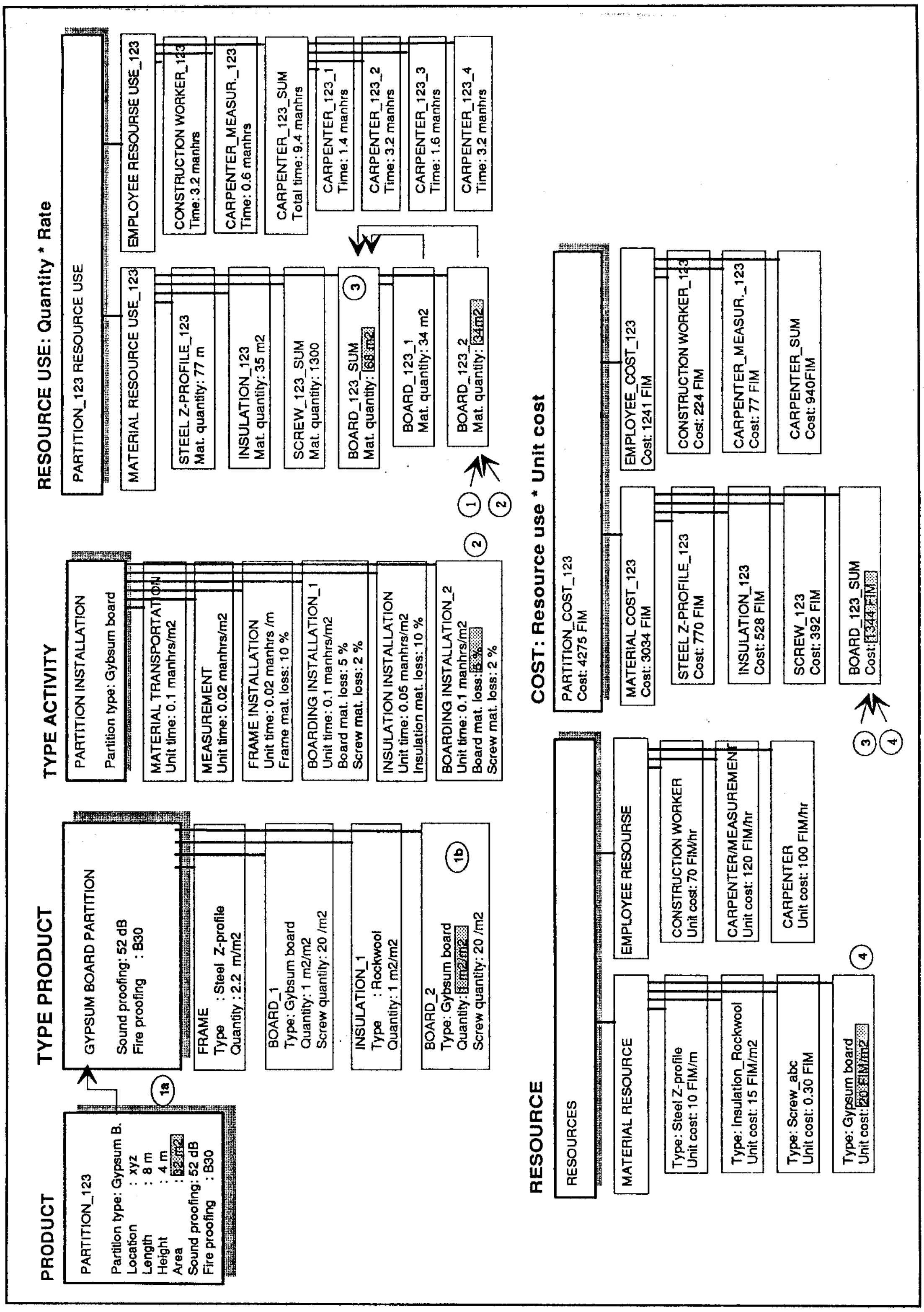

Figure 11. Example of ost estimation of partition wall.

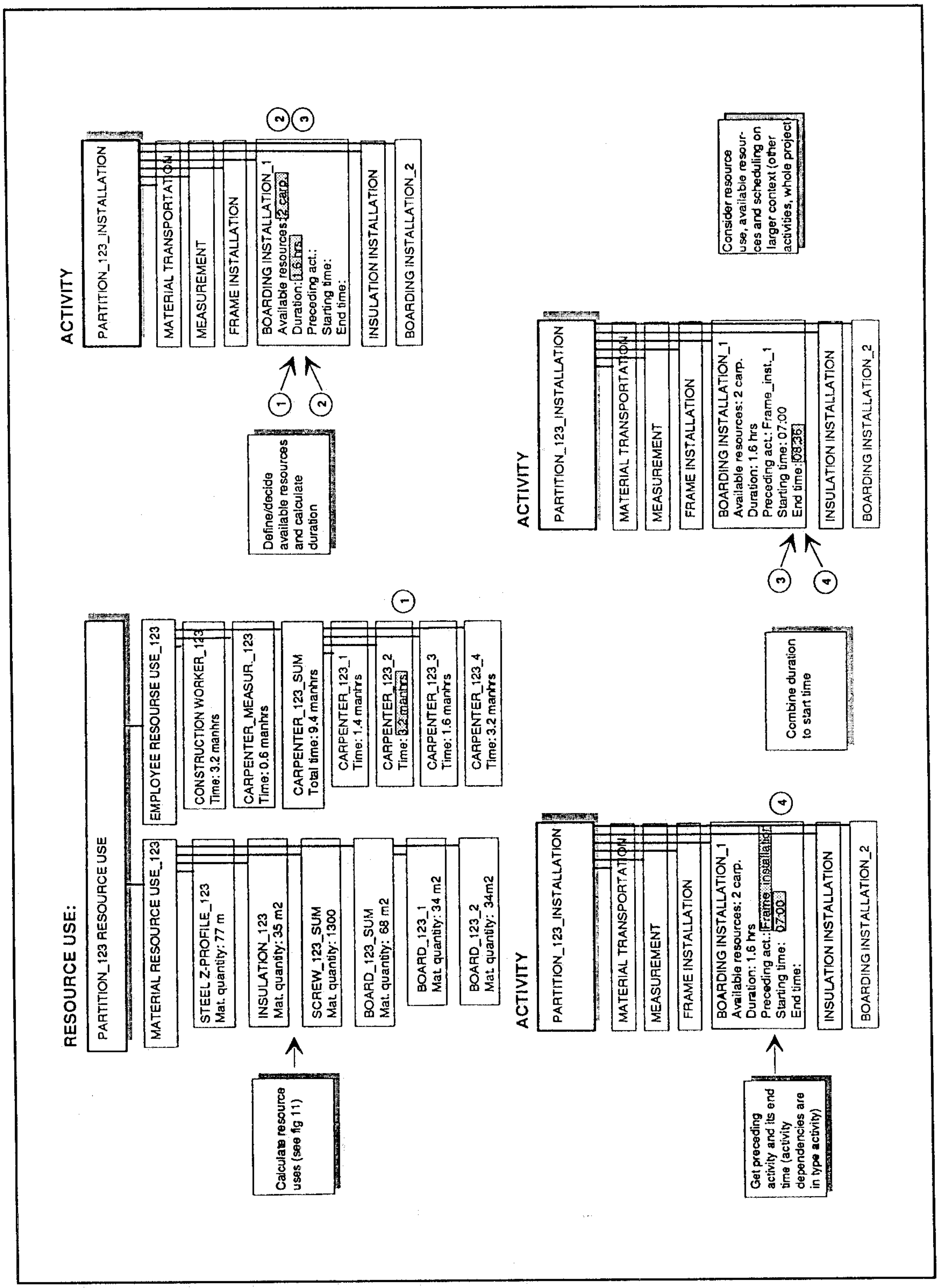

Figure 12. Example of "production planning" of a partition wall (shown only partly, boarding 1).

6. DISCUSSION

In the paper we have tried outline possible extension to the RATAS building product data model which cover other than design information. Among the first extensions to be done could be to add cost estimating aspect to the model in order to bring product modelling and production modelling efforts closer each other.

In this paper only first sketch for product data model extensions are presented and a lot of work remains still to be done and many problems need to be solved. One problem is that the object structure of product data model(s) and the complex relationships are diffucult to visualize and certainly work is needed to develope prototypes combining CAD-systems, hypermedia and databases to make these ideas concrete.

In the short term extending the product data model to cover some aspects of cost estimating and production planning would serve to the data exchange from design to production. Furthermore including organizations, contracts and documents in the model would help in the development of computer aided document management.

In the long term development of a comprehensive conceptual model for all design and construction information provides a sound basis for the development of applications, databases and data exchange in construction and for organizing information management in construction project in a totally integrated way.

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